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Wind energy status of Iran: Evaluating Iran's technological capability in manufacturing wind turbines

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ABSTRACT

Iran, as a developing country, will be confronted with a significant increase in electricity demand in future years. Being a petroleum producing country has resulted in extreme subsidies for energy production from fossilized resources such as oil and gas. This issue is one of the most important factors regarding under-development of renewable energies in Iran. Expansive use of fossil resources in providing the necessary energy has resulted in Iran being among the 20 countries that have a share in the 75% spread of greenhouse gases. This issue has resulted in greater attention on behalf of the energy sectors policy makers regarding renewable energies, especially wind. Awareness regarding the current condition of each system is the first step for optimum policy making. On this basis, analyzing Iran's wind conditions and assessing its technological capabilities is considered a pre-requisite for the wind sectors policy making. This paper aims at studying Iran's wind energy status in the form of available capacities, power production, wind power plant characteristics, principal agents and existing protective laws. Also, the main focus of this paper is on evaluating Iran's potential and effective technological capabilities for producing the main parts of wind turbines in different sizes. In order to fulfill this task, sector-level technological capabilities are defined. Then by analyzing active organizations in this field, Iran's capability level will be determined and by comparing it with the ideal conditions, Iran's technological gaps will be identified. The reasons for the creation of such shortcomings will also be introduced from different aspects in the form of the Atlas model. Finally, Iran's potential capabilities in resolving technological shortcomings will be identified.

Contents

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1. Introduction

Increasing human welfare accompanies have resulted in the development and use of greater and more up-to-date services and products. Manufacturing products and providing services has always required resource consumption. One of the main resources for this aim is energy. In today's societies, one of the important energy types used in manufacturing products and providing services is electrical energy. Therefore, the development of human societies has always faced an increase in power consumption. It is anticipated that henceforth, this increasing trend in electricity usage will continue to go on. In this realm, it is expected that the world electricity usage will reach 32,922 terawatt hours in the year 2035 (approximately two times the amount used in the year 2008) [1].

To be able to respond to the increase in electricity usage in future years, the amount of electricity production should also be increased. Thus, increase in electricity production is one of the prerequisites for the economic growth and sustainable development of countries. Also, with regard to the description of sustainability [2] the economic growth and development model of countries is not considered sustainable on a long-term basis [3–7]. The current policy for producing electricity is also not an exception to this fact. The use of alternative selections with greater sustainability for electricity production can be an asset to the sustainable development of countries. One of the most efficient options in this regard are renewable energies. This is because renewable energies have less environmental effects, are more adaptable, are inexhaustible, and have potential for distributed production. Nevertheless, unfortunately the distribution share of these resources is still low. For example, in the year 2008 the portion of renewable energies in electricity production was 18.5% [8]. Fortunately, the world's inhabitants have become aware of the bad effects of fossil fuel usage and advantages of renewable energies, and it is anticipated that the distribution of these resources will increase in the future [1]. Even in the Middle East region, as the heart of the fossil resource world, it is anticipated that the renewable share in electricity production will reach 16% in the year 2035 from 1% in the year 2008 [1].

Among the renewable energies, wind energy is considered foremost for development. It is anticipated that wind energy, even by preserving the existing conditions[1] until the year 2030, will have a 4.9% share in providing the world's electricity demand [9]. On one hand, this is due to wind-powered energy being one of the more low-cost electricity productions among renewable energy resources [1]. On the other hand, the amount of greenhouse gas distribution as the result of wind-power production is much less as compared to many other renewable energies [10].

Considering the use of wind energy, Iran has a number of advantages. The wind capacity in Iran was initially estimated at about 6.5 GW [11]. With further study, Iran's wind potential has been reported to up to 15 GW (about 35% of the current power production in Iran) [9,12]. As a developing country, Iran is experiencing a rapid growth in power demand. Thus, wind is considered a good resource for responding to this ever-increasing demand. Environmentally speaking, Iran is among 20 countries that have a 75% share in the spread of greenhouse gases [13]. Also the ratio of CO_2 (kilograms) to GDP (US dollars) was a very high 3.15 in Iran in 2008 as compared to the world average of 0.73. The use of fossil fuels is an important factor in the production of these pollutants in Iran [14]. Thus, environmental issues are also an important stimulus for resorting to clear energies and developing related industries such as wind in Iran. Furthermore, the following stimuli can also be mentioned:

- Exhaustibility of fossil resources
- Iran's need for increasing energy safety by giving variety to widespread energy production and other issues
- Using employment opportunities in the future (creating jobs)
- Creating market for raw materials used in wind turbines
- Creating opportunities for exporting products to international markets
- Preventing the outflow of currency
- Economizing on transportation and manpower costs

The aforementioned factors have resulted in Iran's decision for increasing its wind power production. In line with this aim, two main options of onshore and offshore turbine technologies are presented for Iran. With regard to the high capacity available for onshore wind resources in Iran, and also the high costs of offshore turbines compared to onshore turbines, feasibility studies currently carried out in Iran focus on using big onshore turbines. Also, whereas the increase in using wind energy resources is considerable (congress's approval), the local development of the wind industry will also be possible for Iran. But, whereas Iran might be unable to obtain the competitive advantage in producing a number of main parts for the wind turbine, Iran needs to create a system for the capability building in construction of a number of parts. Thus, Iran needs to assess it capabilities in order to support some parts production with prospective possibility for local production on one hand, and high production appeal on the other hand. As a first step, this paper aims at identifying Iran's potential and effective capabilities in producing a number of main parts for wind turbines in various sizes. For this aim, as it will be clarified in the following sections, levels will be defined for sector-level technological capabilities. Then, by investigating the active organizations in the country, Iran's capabilities in producing the necessary parts will be analyzed.

Later on in Section 2 of the paper, the world's wind conditions during the previous years will be specified. Then, in Section 3, Iran's wind conditions will be evaluated. By comparing these two sections, Iran's position in the path of developing wind energy will be clarified. In Section 4, Iran's capabilities in producing necessary parts for building wind turbines will be evaluated using the 10 level model. In this section, Iran's potential and effective capabilities, technological gap ratio with regard to desirable conditions, and reasons for the creation of such gaps will be explored. Finally, results of studies carried out will be presented.

2. World's wind status

In this section, the world's wind energy condition will be analyzed from different aspects. For this aim, the capacity rate affixed in the world and its dispersion, pioneer regions and countries, expenses for producing wind power, number of transactions, creation of jobs, and technological capabilities of the world in building big turbines is analyzed.

[1] This assumption is called "Reference Scenario" by GWEC.

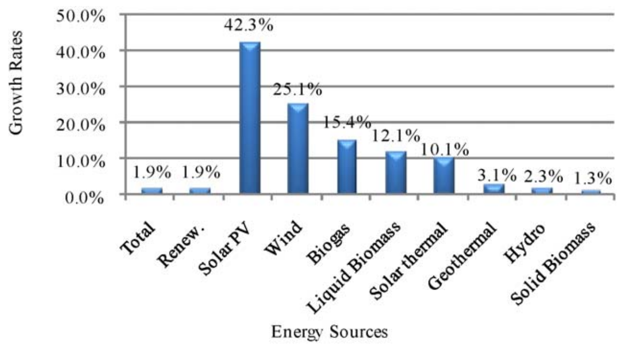


Fig. 1. Average yearly increase rate of renewable supplies from 1990 to 2008 [8].

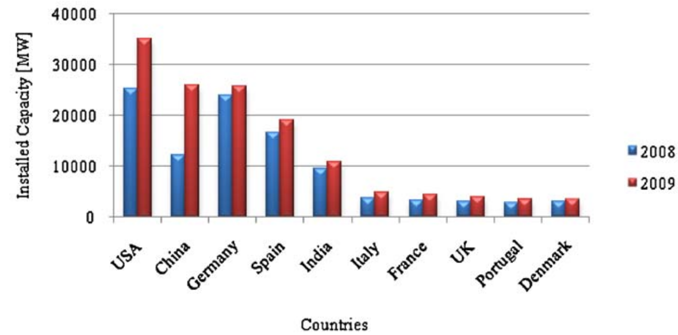


Fig. 4. Top 10 countries in overall installed wind power capacity [15].

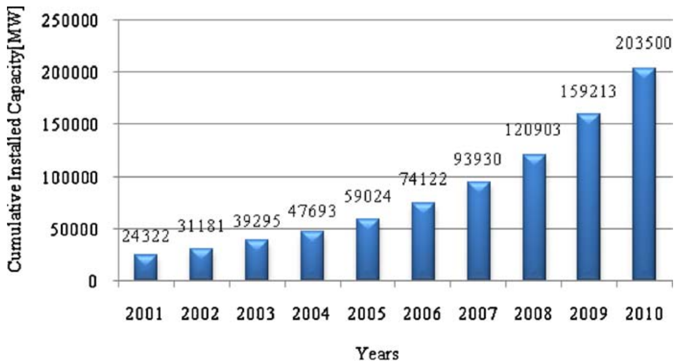


Fig. 2. World's cumulative installed capacity of wind power [15].

During the previous years, among renewable energies, wind power supply has had a significant increase. With regard to Fig. 1, average yearly growth in wind power supply between the years 1990 and 2008 is in second place for renewable energies, with a 25.1% rate [8]. Also, as it is shown in Fig. 2, it is estimated that by the year 2010, the cumulative installed capacity for wind power will reach 203,500 MW [15]. By continuing the current increasing trend, the wind power capacity will double every three years [15]. Also, it is expected that by the year 2030, even by maintaining the current conditions, the installed capacity for wind power will become greater than 570,000 MW [9].

Installed capacity dispersion of the world's wind turbines until 2009 indicates that 48% of the total installed capacity of wind power is in Europe, 25% is in Asia, 24% is in North America, and the remainder exists in other parts of the world [15]. As it is apparent in Fig. 3, this is while among these regions of the world, Asia has had the biggest growth in the year 2009 in wind power capacity increase [15]. With regard to Fig. 4, among different countries of the world, the United States, China, Germany, Spain, and India are among forerunners in installing wind turbines [15].

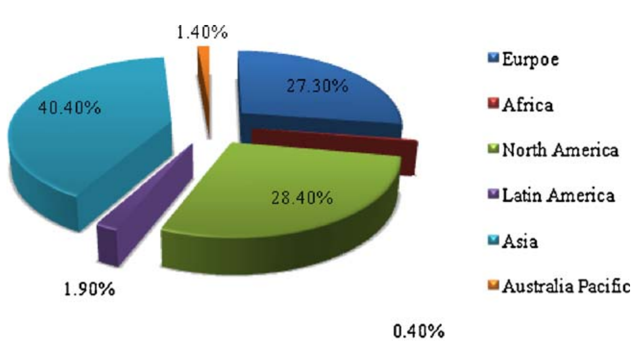


Fig. 3. Different continents' share in increasing wind power capacity in 2009 [15].

Up to now, considerable development related to decreases in power production costs have occurred using wind technology in the world. Today, wind technology is one of the most economical technologies among renewable energies in producing electricity. It is anticipated that this development trend will also continue in the future. The technological development rate during current years has been such that it is claimed the United States will not need considerable development in wind technology until the year 2030 for supplying 20% of its required electricity [16]. As it is evident from Table 1, it is expected that by the year 2035, if new policies are implemented, wind technology will become the second inexpensive technology among renewable energy sources [1].

The transaction rate in the wind sector across the globe reached 70 billion dollars in the year 2009 [15]. Also, the direct and indirect employees of this sector went from 235,000 in 2005 to 550,000 worldwide in the year 2009, and it is anticipated that the number of employees in this sector will reach 1 million people in the year 2012 [15].

During the previous years, the world's capability in building turbines has had significant growth. In the final year leading to the 21st century, the world was witness to 2 MW turbines and by the year 2009, turbines with a capacity of 7 MW were built [10]. Among various regions of the world, Europe has been a forerunner in technological capabilities, and many powerful turbine producing companies are situated in Europe [10].

3. Iran's wind status

Iran, located in the Middle East region, had a population of 72 million in the year 2008 and is a developing country. In fact, Iran is one of the biggest oil and natural gas producers of the world. This issue has also affected the energy structure of Iran, and oil and gas have allocated 44% and 54% of the total energy share, respectively, 90% of the electricity, and 80% of Iran's export share [1,8]. In Table 2, the major economical and energy factors of Iran are compared in

Table 1
Estimated costs of power production from renewable energies between 2021 and 2035 [1].

	Generating costs: 2021–2035 ($2009 per MWh)		
	Avg	Max	Min
Hydro –large	95	136	52
Hydro – small	143	245	70
Biomass	126	142	112
Wind – onshore	65	88	57
Wind – offshore	74	94	59
Geothermal	46	85	31
Solar PV – large scale	157	271	99
Solar PV – buildings	217	356	132
CSP	156	225	107
Marine	187	254	139

Table 2
Major indices of Iran's economy and energy [1].

	Unit	1990	2008	1990–2008[a]
Population	Million	54	72	1.6%
GDP (ppp) per capita	$ (2009)	6767	11,299	2.9%
Energy demand	Mttoe	68	202	6.2%
Energy demand per capita	toe	1.26	2.81	4.6%
Energy intensity	toe per $1000 GDP (ppp, 2009)	0.19	0.25	1.6%
Oil net exports	mb/d	2.3	2.6	0.8%
Natural gas net imports[b]	bcm	−2.0	2.4	n.a.
Electricity consumption	Twh	49	164	6.9%

Note: Mttoe = million tones of oil equivalent. PPP = purchasing power parity. TWh = terawatt-hours

[a] Compound average annual growth rate.
[b] Negative values indicate net exports.

Table 3
Fossil fuel consumption subsidies in Iran [1].

	Unit	2007	2008	2009
Total				
Subsidies	$ billion	64.6	97.7	66.4
Per capita	$	909	1358	895
As a share of GDP (MER)	%	22.6	29.3	20.1
Rate of subsidisation	%	86	90	89
By fuel				
Oil products	$ billion	36.6	52	30.1
Rate of subsidisation	%	86	90	88
Natural gas	$ billion	18.8	30.5	24.8
Rate of subsidisation	%	93	94	95
Electricity	$ billion	9.2	15.2	11.4
Rate of subsidisation	%	77	84	82

1990 and 2008 [1]. As it is observed from Table 3, due to oil and gas assets in Iran, considerable subsidies are added to oil and gas energy. This is an important factor for non-development of alternative energies, such as renewable energies in Iran. Nevertheless, Iran's government is planning to lift the subsidies. If this plan is fulfilled and prices are amended, competition and thus the appeal of renewable energies, especially wind will increase greatly [17].

Iranians were the first people to create added value of wind energy using windmills. A number of these windmills which date back to 2000 years B.C., are still at work in some rural regions of Khorasan province. Due to its geographical location and heterogeneous climate, Iran has good wind resources. With regard to the wind energy classification carried out by America's energy department, many of Iran's wind sites are in the 7th ranking of this classification-situated in the 800–2000 (W/m^2) range [18]. In the previous years, Iran's wind capacity was estimated at about 6500 MW [11,18]. However, after current analyses, a 15 GW potential is estimated for Iran [9,12]. Wind potential-measurement studies of Iran are being completed and it is anticipated that this statistic may reach 40 GW [19]. In Figs. 5 and 6, the dispersion speed and wind capacity of Iran is shown at an altitude of 80 m. Iran also has the potential of using offshore wind energy [20]. This is while Iran had only about 89 MW of installed wind capacity until the year 2008 [21]. Whereas Iran's neighboring country, Turkey, having about 10 GW of economic wind potential had installed 1300 MW of installed wind power by the year 2005 and it is anticipated that this capacity will reach 2800 MW by the end of 2010 [22]. Iran's increasing wind power capacity trend during previous years is shown in Fig. 7 [21].

Most of Iran's sites are situated in Gilan and Khorasan provinces. Studies are also currently being carried out for the exploitation of wind resources in Qazvin province. As it is shown in Table 4, 157 projects with a capacity of 89,830 kW are being operated and another 98,820 kW are under study [21].

Currently there are four wind power plants named Manjil, Binaloud, Dizbaad, and Sahand in Iran. Information related to these power plants is summarized in Table 5.

Considering the installed wind capacity, by the end of 2009, Iran had the world's 38th ranking [15]. This ranking is not sufficient for Iran with regard to available wind capacities and abundant wind power development stimuli. As mentioned before, one of the most important growth obstacles in using this energy is Iran's oil-bearing

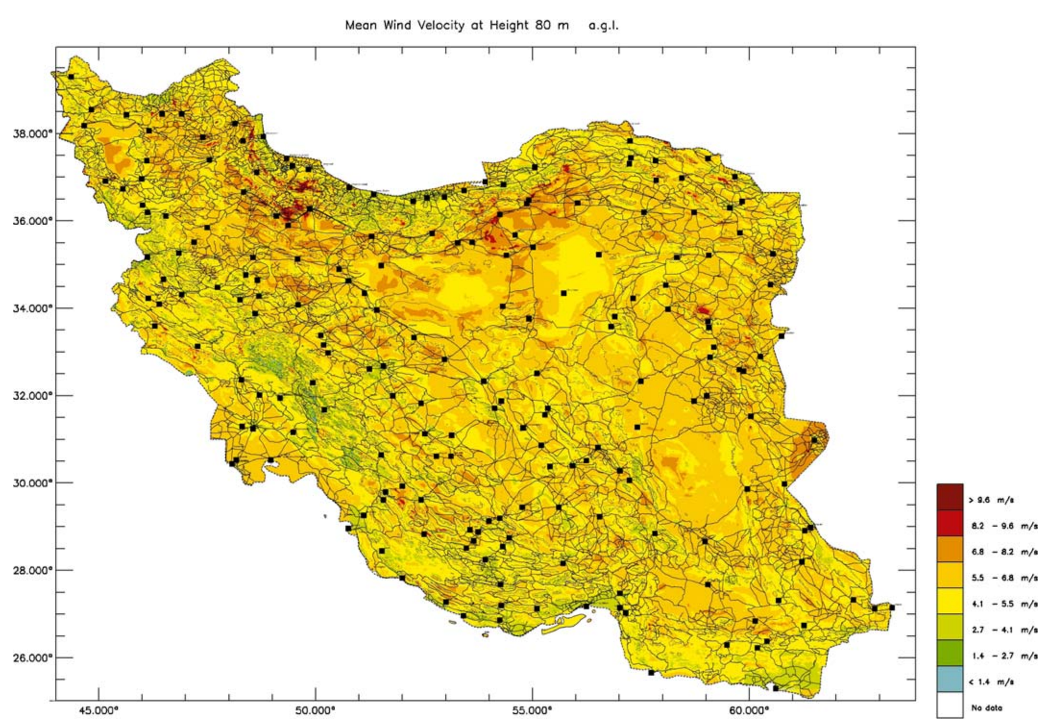


Fig. 5. Iran's wind speed dispersion at an altitude of 80 m [23].

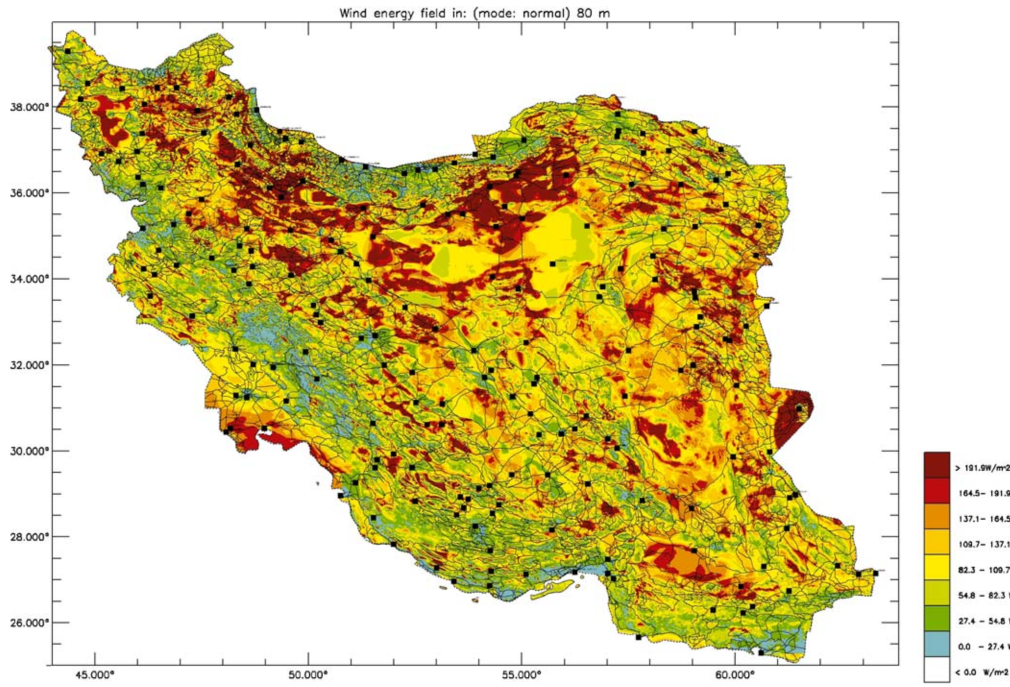


Fig. 6. Iran's wind capacity dispersion at an altitude of 80 m [23].

Table 4
Iran's wind projects in 2008 [21].

Province	Under exploitation		Executive and research	Total	
	Number	Capacity (kW)	Capacity (kW)	Number	Capacity (kW)
Gilan	111	61,180[a]	388,820[b]	111	100,000
Qazvin	–	–	60,000	–	60,000
Khorasan	45	28,640	–	45	28,640
East Azarbayjan	1	10	–	1	10
Total	157	89,830	98,820		188,650

[a] The capacity of the aforesaid plans is in line with constructing 100 MW of wind powered turbines in the Gilan and Qazvin region.
[b] In the year 2008 no project was under implementation, however, based on the agenda, it has been agreed that in 2009 and 2010, a 660 kW turbine of 32 units will be utilized in the Gilan region.

Table 5
Characteristics of installed wind turbine sites in Iran [21].

Wind power plant	Site	Province	City	Installed turbines	
				Number	Capacity (kW)
Manjil	Babaian	Gilan	Roudbar	1	600
	Paskoulan	Gilan	Roudbar	22	14,520
	Roudbar	Gilan	Roudbar	4	2150
	Siahpoush	Gilan	Roudbar	26	17,160
	Manjil	Gilan	Roudbar	31	13,250
	Harvil	Gilan	Roudbar	27	13,500
Binaloud		Khorasan	Neishabour	43	28,380
Ventis (Dizbaad)		Khorasan	Neishabour	2	260
Sahand	Sahand Tabriz Univ.	East Azarbayjan	Tabriz	1	10
Total		–	–	157	89,830

characteristic. The significance of this factor is specified by comparing Iran with other oil-bearing countries in the Middle East. By studying the existing oil-bearing countries in the Middle East, it is observed that these countries also have not sufficiently dealt with developing wind energy. Even in the Middle East region, Iran is the only country to have installed wind power on a large scale [9]. Nevertheless, it seems that in the near future, the Middle Eastern countries will resort to renewable energies [24]. Iran also needs to use its potential and attempt at compiling a multilateral plan for benefiting from this energy resource.

There are different participants involved in Iran's wind sector. These participants can be identified in the public, academic and industrial[2] sectors. Public sectors attempt at fulfilling 4 roles: policy making, regulating, facilitating and service providing. Based on this classification, Table 6 shows the existing participants in the public sector of Iran's wind industry according to their function.

[2] This model is called "Triple Helix" in literatures.

Table 6
Participants in the public sector of Iran's wind industry.

Function	Policy making	Regulating	Facilitating	Service producing
Organization	- Expediency Discernment Council - Congress - Ministry of Energy - Presidential Office of Science and Technology - The council of state - Headquarters for technological development of renewable energies - Supreme Council of the Cultural Revolution - Supreme council of science, research and technology - Ministry of Science, Research and Technology	- Congress - Tavanir Organization - Presidential office of planning and strategic supervision - Environmental Protection Organization - Ministry of Industry - Ministry of Trade - Renewable Energy Organization of Iran - Natural Resources Organization	- Presidential office of technological cooperations - Ministry of Commerce - Ministry of Industry - Ministry of Trade - Renewable Energy Organization of Iran	- Renewable Energy Organization of Iran - Organization for Electrical Development - Natural Resources Organization - Presidential office of technological cooperations

In the academic and research sector related to Iran's wind industry, various centers can be introduced as participants of the service providing function. These participants include: Iran's Industrial Scientific Research Organization, Energy Research Institute, Energy Technology Development Center, Environmental Energy Research Center, Research Institute of Planning and Management, Center for Environment and Energy Research Studies (CEERS), International Energy Studies Institute, Shahid Abbaspour Power and Water University of Technology, Higher Education Institute of Applied Science in Water and Power Industry, Sharif University Department of Aerospace Engineering, Tehran University Department of Mechanics, and Zabol University.

Table 7 shows the names of different participants in the wind industry based on functional values of providing services. As it is observed in Table 7, Iran's wind industry is not systematically formed and there are few participants in the various sectors of its wind industry.

In Iran, some laws have been regulated in order to support renewable energies. But support given till now has not been sufficient and necessitates improvement and reform. Some of the steps taken for supporting renewable energies in Iran are as follows:

- Attempting for achievement in technology and knowledge of modern energy and creating wind and solar power plants and geothermal and fuel cells in the country.
- Giving discounts for customs duty: this law has been legislated for implementing discounts on customs duty and commercial profits of foreign parts necessary for building wind turbines.

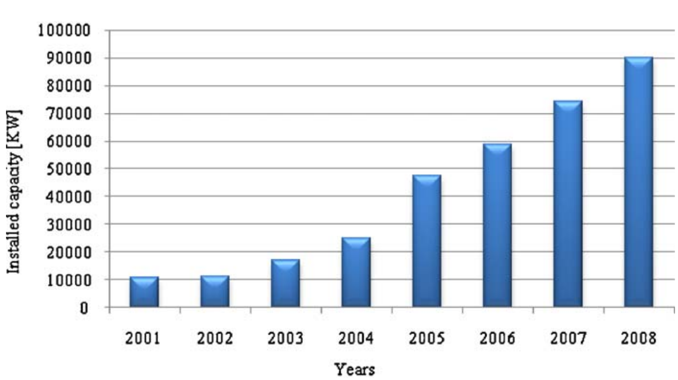


Fig. 7. Installed accumulated wind power capacity in Iran between 2001 and 2008 [21].

- Guaranteed purchase of wind power: this law focuses on trade preparations for power produced from renewable energy resources, guaranteed and with feasible costs. Guaranteed purchase price is equal to 1300 rials/kilowatthours at peak and average hours and 900 rials/kilowatthours for low charge hours.
- Necessity for producing renewable energy: producing renewable energy has been made mandatory by the end of the fourth economic social development plan of the country as 1% of the countries total.
- Necessity for Ministry of Energy to carry out charges related to the use of new energies with the support of the private sector.
- Necessity for the Ministry of Finance to pay the purchase charge of produced energy of the private sector with a priority for water energy production and renewable energies.

In addition to the aforementioned laws, the law for purposeful subsidies in Iran and the 44th principle of Iran's constitutional law also has an indirect effect on the development of renewable energies. The national record for Iran's renewable energies is also being compiled.

4. Evaluating technological capabilities of Iran's wind industry

4.1. Methodology

Technological capability can be considered as all strengths necessary for carrying out activities related to production [25]. There is no doubt that increase in technological capabilities has an important and vital role in industrial development and increase in social welfare. Solo [26] has shown that 87% of the obtained increase in each person hour between 1909 and 1949 in the United States was due to technological development. In addition, the advancement of technological capabilities is considered a factor for competitive advantages among nations [27]. In fact, with the existence of technological capabilities, two other types of capabilities in each country including physical investment and human asset will be completely efficient [28].

In order to increase technological capabilities of countries in line with the increase in national interest investment is necessary. This issue is more significant for developing countries such as Iran. The technology policy process includes various sub-processes. One of its subprocesses is technology auditing [29]. Technology auditing is analysis for identifying weak and strong points related to technological asset [30]. In order to carry out technology auditing, it is also

Table 7
Existing participants in Iran's wind industry.

Installation and operation		Participants in the part construction domain					Consulting domain and wind turbine design participants	Participant group
Operators	Providing installation equipment	Generator	Gear box	Hub	Tower	Blade		
Manjil Green Electricity, Binaloud Green Electricity	Nasb-Gostar, Nasb-Niru, Saba Niru, RampCo, Tak Machinery Technologists, Mangan	Fan-Generator, MAPNA Generator	Saipa Industrial Molds, Tarhnegasht	Irfo, Sanat Bishe, Arak Machine Manufacturing Esfahan Dor	Sadad Machine, Azarab, Arak Machine Manufacturing, Mahshahr Pipeline Manufacturing	Saba Niru	Saba Niroo, Moshanir, Energy Institute, Ghods Niru,	Participant name

necessary to evaluate technological capabilities [31]. Therefore, evaluating technological capabilities as one of the prerequisites for adopting substantial decisions related to the improvement of technological capabilities of a system (firm or higher establishment) is put forth.

Technological capability evaluation can be carried out in various levels. For example, Lall [28] generally considers two types of technological capability: National-Level Technological Capability and Firm-level technological capability. Nevertheless, as it is shown in Fig. 8, Hobday analyzes technological capability in three strategic levels for developing countries in order to acquire applicable technology. (1) National (2) Regional (3) Firm or commercial company [32]. Thus it can be stated that the outcome of companies' capabilities in promoting and producing specific industrial products forms the technological capabilities of that country in that certain industry.

Steps which are commonly taken for evaluating technological capability are as follows [31]:

- Evaluation of technological gap: after designating a goal or desirable aim to acquire, the existing situation must be assessed and compared with that.
- Evaluating factors that influence technological gap: the existing gap between the current and desirable condition was the result of factors which are called technological deficiency. Thus, technological deficiencies are a set of factors which prevent the system from achieving its desirable aim. In order to formulate strategies for improving the system, technological deficiencies must be identified.
- Evaluating the system's ability in eliminating technological deficiency: compiling policies for the system's improvement without awareness of the system's ability will cause deviation. Thus, the system's potential ability in eliminating some or all technological deficiencies should also be evaluated as the input for related decision making. In fact, this capability is the system's potential capability.

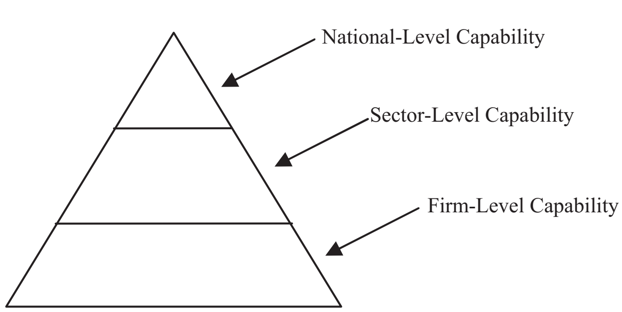


Fig. 8. Framework for evaluating technology demands: Three strategic levels of technological capability [32].

In order to carry out various steps in the evaluation process of technological capabilities, different tools have been developed. Most of these models have developed at the firm level. Therefore, many of the existing models require the input of data with considerable details. Thus, in order to use existing models at the sector level, models should be used which require the input of data without considerable details. Table 8 gives a brief explanation of these models:

Among the models introduced, only the Atlas Model is applicable at the ultra firm level [31]. In addition to the mentioned models, a number of researchers have presented models based on technological capability levels on the national scale which can be the groundwork for evaluating the technological capability of Iran's wind industry. For example, Wolcott et al. [39] have introduced the following levels for identifying the depth of technological development:

- Level 0: (Use) No development takes place in the country. If technology exists, it has entered as a final product.
- Level 1:(Assembly) Simple assembly of parts; minimum or no innovation of product or process.
- Level 2: (Conformation) Relatively complex development and production is carried out with extensive foreign cooperation, probably by obtaining a license. Efforts might be made to conform to national conditions.
- Level 3: (Advancing) Local companies are actively attempting to improve a number of development stages of relatively new technology (not necessary all stages). For example, fundamental research and product design might take place outside of the country, but local companies are active in innovating the process and other stages of post-design.
- Level 4: (Comprehensive) Fundamental research, applied research, design and development, innovation in process and final production are carried out inside the country. Technologies and supportive services are often inside the country. In this case, the country is completely capable of carrying out all stages inside the country, but due to certain economical or political reasons, obtains results of a development stage from another country.

In this paper, in order to evaluate the technological gap, a level 10 model based on levels presented by Wolcott et al. [39] has been developed. After analyzing the technological capability evaluation of Iran's wind industry for main parts of big wind turbines with capacities of up to 1.5 MW, between 1.5 and 3 MW and bigger than 3 MW, based on available data related to its firms, the reasons for technological gaps are stated in the form of the Atlas Model. One of the most important advantages of this model is its simplicity and comprehensibility for decision makers. Four different aspects for identifying reasons for the creation of technological gaps in the Atlas Model are as follows [35]:

Table 8
Technology auditing models.

Model or method	Explanation	Source
Value Chain of Activities	In order to assess the technological capabilities, activities in which these abilities are concealed will be evaluated. These activities will be compared with similar challenging activities.	[27]
Panda and Ramanathan Method	Four sets of criteria are introduced for carrying out evaluation and standards are introduced for each. Then firms are compared based on these standards.	[33]
Direct Assessment of Technological Capability	Levels are introduced for technological capabilities which the author calls positions. The position of each firm is compared with the position of competitors or the ideal situation.	[31]
Atlas	Based on the four perspectives of technology components, the technological capability of one firm or one country is evaluated. Based on these four perspectives, the index is defined for the technological capabilities of the system in mind.	[35]
The Technology Management Audit	Includes a set of guidelines for identifying and selecting technological opportunities and analyzing causes of technological gaps in the firm.	[36]
Technology Management Process Assessment	By identifying important occupation unit, technology management activities are identified in a certain framework. Afterwards, these activities are assessed.	[37]
Technology Audit Model (TAM)	This model, which includes a set of standards for technology audit, attempts at analyzing the company's position in technology management.	[30]
Lin Method	This method proceeds at analyzing technology management capability with focus on technology acquisition through transfer. On this basis, 6 sets of criteria are identified and indexes are defined for each. Then, based on these indexes, the firm's capability in transfer of technology is evaluated.	[38]

- Technoware: manual tools, powered equipment, general purpose machines, special purpose machines, automatic machines, computerized machines and integrated facilities.
- Inforware: familiarizing facts, describing facts, specifying facts, utilizing facts, comprehending facts, generalizing facts and assessing facts.
- Humanware: operating ability, setting ability, repairing ability, reproducing ability, adapting ability, improving ability and innovating ability.
- Orgaware: individual linkages, collective linkages, departmental linkages, enterprise linkages, industrial linkages, national linkages and global linkages.

Finally, Iran's potential in obviating technological deficiencies in the form of the level 10 model is presented. The development model given in this study is separated into 9 levels as follows:

(1) **Unawareness of application**: in this level of technological capability, there is no information regarding application and usage of the product inside the country.
(2) **Awareness of application:** in this level of technological capability there is information regarding how to use the product.
(3) **Usage ability:** in this level not only is there awareness of the products applications, but abilities to use the product have become effective.
(4) **Repair and maintenance ability**: in this level other than the ability to use the product, repair and maintenance of the product is made possible and there are individuals or groups in the country who can maintain and repair the products.
(5) **Assembly ability**: in the fifth level of technological capabilities, the country has assembly abilities for product components and building the final product. In other words, the country is able to produce the necessary parts for wind turbines by assembling its parts.
(6) **Production ability by duplicating design**: in this level in addition to assembly abilities, duplicating the design of the necessary part from available samples are possible.
(7) **Production ability with a percentage of domestic design:** in this stage of technological capability, the ability to domestically design parts of the existing sample according to the countries qualifications is made possible.
(8) **Production ability with 100% domestic design**: in this stage of technological capability, the ability to domestically design the part and then produce it is made possible. In other words, the country can independently design and produce the part without duplication of other samples.
(9) **Applied research ability**: in this phase, in addition to the above-mentioned abilities, the capability to implement applied research also exists inside the country.
(10) **Fundamental research**: in the final level of technological capability, the potential for fundamental research regarding the required part of the wind turbine exists.

One of the aspects of national economic interests is increasing the countries technological capabilities. Therefore, adopting major decisions needs to be in line with maximizing the national interest. In addition, research and development clearly plays an important role in all phases of the innovation process [40]. Also, in case capability is not able to be reached will the 6th level of the levels introduced, significant research and development has virtually not occurred. As a result, technological capabilities of a country will not increase to a great extent. Thus, in order for Iran to develop its wind industry in line with maximizing the national interest, it needs to reach the 6th level of the capability levels introduced in this section.

By designing the methodology necessary for evaluating technological capabilities, the parts to be studied can be selected. In order to do this, the main parts of the wind turbine are identified. The wind turbine assemblage consists of four main components as follows: foundation, tower, nozzle, and rotor. Among these components, 14 parts are chosen as the main parts of the analysis process of the countries capability in the realm of wind turbine technology. The main components analyzed are as follows: blade, plug blade (hub), main shaft, gearbox, disc brake, tower, generator, bearing, transformer, foundation, control and screw system and yaw, chassis and ball bearing.

Fig. 9 shows these components separately in wind turbines. Among the mentioned parts and electrical parts, some parts have international standards which are usable in many industries and are provided as imports. Basically, economically speaking mass production of these parts is not justifiable. Thus, due to the limitation on Iran's market and inability to mass produce these parts, the competitive advantage does not exist for Iran and their naturalization inside the country is not justifiable. Among these parts, the most important parts in the wind turbine assemblage are the bearing and ball bearing.

A number of other parts mentioned are also not specific to the wind industry and are used in other industries and Iran has good capabilities in producing these parts, whereas many parts of this

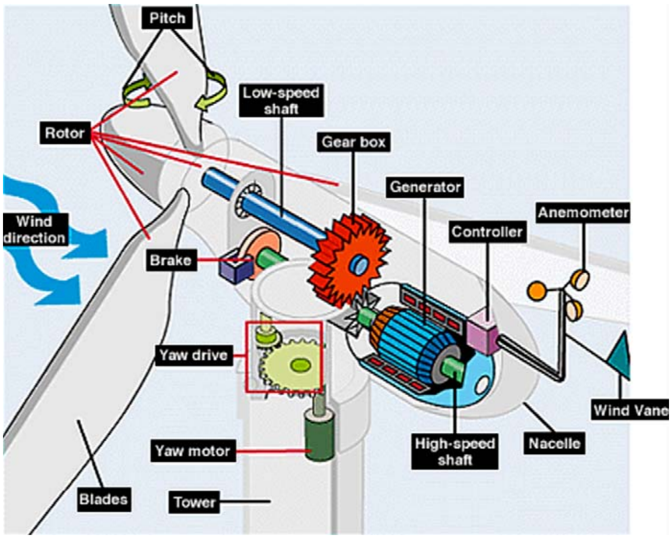


Fig. 9. Main parts of the wind turbine [41].

type are produced and used in other industries. Thus, these parts are not analyzed in this study. The most important part which is among this group included the foundation, transformer and electrical parts, yaw gear, main shaft, and chassis.

- Erecting the foundation of wind turbines is a constructive task which is also utilized in other industries and strong companies in the country are actively operating in this realm.
- The transformer and electrical parts of the wind turbine are also applied in other power plants and various realms and are not specific to the wind industry. The country also has suitable capabilities in this domain.
- Regarding chassis, yaw ball bearing, and main shaft it can be said that parts of these dimensions are also applicable in industries such as cement, petroleum and gas and numerous companies have grown and developed in this domain.
- In general, parts which are particular to the wind industry and are less applicable to other industries and the countries capability needs to be analyzed more exactly regarding these parts, include: tower, gearbox, generator, hub, control system, screw and yaw, and blade. In the following sections, each one of these parts is separately analyzed.

4.2. Evaluation

In this section, Iran's ability in constructing each of the main turbine parts in various sizes is evaluated. For this aim, capable domestic constructors and manufacturers are initially identified in the realm of producing wind turbine parts. By evaluating the equipment, potentials and obstacles hindering each company in producing wind turbine parts with various capacities, and a comprehensive understanding of each company's capabilities in producing parts is obtained. Based on the understanding achieved and by summing up the companies capabilities in constructing each part, the potential and effective technological capabilities of the country in constructing big wind turbine parts with capacities of less than 1.5 MW, between 1.5 and 3 MW and more than 3 MW have been specified in the form of the 10 level model of technological capability. Also by categorizing obstacles hindering the companies in naturalizing the parts, the main reasons for the country not achieving the ideal level of technological capability (construction with a percentage of naturalized design) in the form of the Atlas Model has been identified. In the following section, results obtained from these analyses have been presented in the form of the country's technological capabilities in naturalization according to each part.

4.2.1. Tower

Wind turbine towers, have various types of concrete towers, metal towers, and hybrid towers. This part is less complex than other parts and its production process is much simpler. In Iran, various companies including Sadid Machine Co., Sadad Machine, Azarab Co. and Arak Machine Manufacturing are working in the realm of tower construction. There are two important parts in the construction of wind turbine towers, and considering the country's capability, the ability for building these parts exists inside the country. These parts are the flange and plates used in building the tower. Flange is a standard part and thus there is no problem in its construction process. Flange is built in small dimensions in Iran. In the realm of constructing plates, despite more difficult conditions, the potential in producing plates with width of 4 m is also possible. Other than these two main parts, the electric box and wiring inside the tower are all produced in Iran. With regard to the country's potential and capability in the realm of metal plate rollers, it does not appear that Iran would have any specific problems in constructing this part. Presently, flanges used in building the 660 kW V47 wind turbine tower have been imported with a reasonable price. Thus, its production for current capacities is not economic and the capacity of other industries must also be considered. All in all, it can be concluded that Iran is highly capable in designing and constructing this part.

With regard to the capabilities put forth, it can be concluded that Iran has significant capabilities in the realm of building wind turbine towers. The potential and effective capability level of Iran in building wind turbine towers is shown below:

	>3 MW	1.5–3 MW	<1.5 MW
Potential	Construction with a percentage of naturalized design	Construction with 100% naturalized design	Construction with 100% naturalized design
Effective	Construction with 100% duplicated design	Construction with 100% naturalized design	Construction with 100% naturalized design

Whereas hybrid towers are used in constructing 3 MW wind turbine towers, the country is potentially at a "construction" level with a percentage of naturalized design regarding the construction of this part, but it can effectively be considered at the 100% capability level of naturalized design of these types of towers during the next five years. It is noteworthy that as the size of these wind turbines increases, the plate dimension will also increase. In fact, if facilities and equipment exist, there will be no problem in constructing towers in the country. Thus, the only obstacles hindering the achievement of higher level naturalization are technoware problems.

4.2.2. Gearbox

The gearbox is a part which is connected to the rotor turbine on one side and the generator in the other and results in increase of the low rate rotor drive (tens of rotations per minute) to an amount proportional to high speed generators. Existing gears in the gearbox have a rating from 1 to 10 and by increasing the grade, the precision of its dents is decreased. In the wind turbine gearbox, gears with a grade of 5 and 6 are used. Various companies in the world are producing this part for wind turbines. Among the most important potential companies inside Iran in the realm of building gearboxes for wind turbines, Alkan Machine Co., Tarh Negasht and Saipa Industrial Molding Co. can be named. A number of Iranian companies have advanced machinery for building gears such as machines for building spiral bevel gear and profile grinding gear in

different sizes and machinery for Involutes testing gear and pressure angle (such as KLINGELNBERG and HOFLER). Some of these companies have the most up-to-date software systems in the field of design, analysis, optimization, and controlling mechanical gear elements and gearboxes such as GUDIO software (designed in the country), KISSSOFT, KISSSYS, and KISSQS. Besides these capabilities, Iran having capable professional forces has potential abilities in designing and building gearboxes for various applications such as wind turbines. However, due to the limited demand for wind turbine gearboxes, the strength in mass production of this part has not been made available. Until now, these companies have been successful in designing and producing kilowatt wind turbine gearboxes by reverse engineering. In this method, some gearbox components have been provided for with the cooperation of a number of domestic companies and other from foreign countries. Currently, Iran has the capability of building gears with a grade of 5, while it is now carrying out construction projects of 6 sample solar gears for wind turbine gearboxes. By installing the first 660 kW V47 wind turbine gearbox, and with regard to its experience and knowledge gained in this field, Iran will soon obtain the capability of mass producing this product. If the country achieves the capability to build the gear for the wind turbine gearbox of less than 1.5 MW, the construction of this type of gear for 1.5–3 MW turbines will become possible.

By analyzing domestic companies' experiences regarding equipment and facilities for constructing wind turbine gearboxes, Iran's technological capabilities can be evaluated as follows:

	>3 MW	1.5–3 MW	<1.5 MW
Effective Potential	Assembly Construction with a percentage of naturalized design	Assembly Construction with a percentage of naturalized design	Assembly Construction with a percentage of naturalized design

If the entire gearbox production process is divided into two sections, it can be said that Iran is effectively capable of design but does not have the capability for manufacturing. Also, by carrying out analyses at the level of active companies, it can be concluded from a technoware perspective, that there are only two companies in Iran with machinery abilities with dimensions greater than 1 m (appropriate for gears of wind gearboxes). To a certain extent, this is considered a gap in the capability of a country. Also due to inaccessibility of some primary substances, ability to build a number of gear components for turbine gearboxes does not exist in the country which is natural. The domestic construction of gearboxes does not mean the 100% construction of parts inside the country. Usually 20 to 30% is provided from foreign countries. From the Infoware perspective, only two companies are equipped with software related to designing this part. Thus, the Infoware gap is also observable to a certain extent in this dimension of capability. Also, lack of sufficient demand for wind turbine gearboxes in the country and incapability at creating a market has prevented Iran from reaching the ideal capability level and has created a gap from the perspective of Orgaware. Contrary to the gap in various dimensions of capability, regarding professional and technical human resources (Humanware) in designing and constructing this part, Iran has an acceptable status.

4.2.3. Generator

A generator is the most important electrical system in wind turbines which has the function of transforming mechanical energy from blade rotation to electrical energy. In Iran, various companies are operating in the realm of power plant generator construction, synchron generators used in railway transportation and high pressure electrical motors. These companies are considered the only potential options for building wind turbine generators. Among the most important of these companies are Fan Generator Co., Pars Generator, Gem Co., Turbo Generator, and Roshd Sanat Niroo. In the realm of building generators, Iran is equipped with the equipment and various machinery (such as the coil screw machine, core notching machine, induction brazing machine, and balancing machine), software capabilities (such as AUSTER, SMART, and Winding Diagram for designing wind turbine generator parts) and professional man power. In the realm of building wind turbine generators, Iranian companies have been successful in developing their knowledge through transferring technology and assembly under license by cooperation with reputable companies in the realm of generator production. Iran receives these generator parts as a Complete KnockDown (CKD) and other operations such as rotor winding and stature, resining, curing, assembly and testing are carrying out inside the country. With previous experience in this realm, Iran entered the pilot construction of the first sample 660 kW wind turbine V47 generator. In constructing this product, all parts were produced in the country and only raw materials such as insulators, core sheet, and bearings for the construction process were provided from abroad. Currently the first sample of the 660 kW generator was produced and put into operation in Iran. Based on domestic abilities, and building the first sample of this generator (pilot) and gaining the experience and knowledge of constructing this product, Iran has the capability of building 660 kW V47 wind turbine generators. With regard to experience in building wind turbine generators, Iran also has potential capabilities in building 1.5–2 MW generators in the near future. All in all, it can be concluded that Iran faces problems regarding the design and manufacturing of wind turbines, effectively, and these problems will be resolved with time and experience.

With regard to the understanding obtained from capabilities of Iranian companies in the realm of building various generators, especially wind turbine generators, Iran's technological capabilities in building generators can be summarized as follows:

	>3 MW	1.5–3 MW	<1.5 MW
Effective Potential	Assembly Construction with 100% duplicated design	Assembly Construction with 100% duplicated design	Assembly Construction with percentage of naturalized design

By reviewing the potentials of domestic companies, it can be clearly observed that considering Infoware and Humanware, Iran has high capabilities in constructing parts. From the technoware perspective, there is also no serious problem in building megawatt turbine generators for companies (other than providing a number of standard parts from other countries). Thus, the most important reason for Iran's inability to currently obtain the ideal level of capability is the lack of demand in the market (Orgaware) and following that is the lack of production experience for wind turbines which will be fulfilled in the near future with the increase in demand.

4.2.4. Hub

Hub is a part which connects wind turbine blades to the main axis. Among other production methods such as welding, machining, and heat treatment, one of the most important key methods for building this part is the use of casting methods. Various companies have the ability to operate in this field. Among Iranian branches active in this field Sanat Bisheh, Arak Machine Manufacturing Co., Azarab Co. and Sadid Casting can be indicated. Iran, having a professional task force and necessary equipment such as melting furnaces with capability of melting 15 tons, produces a variety of ductile cast iron for various purposes. With these capabilities, domestic companies are now one of the main hub providers for 660 kW V47 turbines for Saba Power Co. Thus, with regard to the countries casting abilities, it can be said that there is no problem in the path of the wind turbine hub construction process. In

summary, the countries' overall potential and effective capability in the field of part construction can be evaluated as follows:

	>3 MW	1.5–3 MW	<1.5 MW
Potential	Construction with 100% naturalized design	Construction with 100% naturalized design	Construction with 100% naturalized design
Effective	Construction with 100% naturalized design	Construction with 100% naturalized design	Construction with 100% naturalized design

It is noteworthy that as the turbine size increases, its hub production rate will necessitate high capacity furnaces of which Iran has the ability to build all of them and nearly no Technoware, Infoware, Humanware, and Orgaware problems exist in this realm.

4.2.5. Control and screw system and yaw

The control and screw system and yaw are among other sections of the wind turbine, each having their own specific function. The control system is responsible for controlling most components of the turbine such as blade angle adjustments, turbine direction adjustments, specifying the off/on timing of the turbine in certain conditions. This part is comprised of a main processor (CPU). The screw system is responsible for transmitting the momentum resulting from the wind power on the blades to its maximum, especially in conditions where wind speed is low or high. Finally, the yaw system causes the main axis of the nacelle to rotate according to the wind's direction. Various companies are operating this field among which the most important can be referred to as Contronik Co. Of sample records from domestic companies in this field, one can refer to having experience in the field of constructing PLC's of control systems and various CNC's, and also the capability of designing and implementing various softwares. Overall, Iranian companies, having facilities such as PLC production lines, product testing labs, strong research and design units, and engineering and enforcement unit, possess the necessary capabilities for building control systems and wind turbine screws. The naturalization process of this wind turbine part, similar to other parts, includes two main sections of design and manufacture. Designing this system is the most important part of wind turbine production. The design process of this system includes six phases which are as follows:

- Designing a control system according to the turbine model
- Designing controlling loops (related software)
- Simulating software
- Credibility evaluation
- Implementing software on PLC's
- Designing the protocol

Iran does not currently have effective capabilities in the realm of credibility evaluation of the designed system and designing control systems similar to the turbine model. In designing the control and screw system for wind turbines, the individual or design company must have the necessary experience related to various forces inflicted upon the turbine during production, and this necessitates the company having direct relations with this system during the production process in order to identify the various forces inflicted upon the turbine.

In the production process of this part, due to unavailability of necessary parts (from foreign countries), there will be no serious problem for Iran. In order to build this part, Iran must provide various parts such as different types of IC's, connectors, sensors, and electrical parts from foreign countries. Overall, Iran is capable of building 80% of the control and screw system. The most important products related to wind turbines built in Iran are the PLC500 Nseries and DC & AC Drives.

With regard to the capabilities mentioned for Iranian companies and their experiences in constructing technologies related to this wind turbine part, the naturalization level of technological capability for Iran can be defined as follows:

	>3 MW	1.5–3 MW	<1.5 MW
Effective	Awareness of Use	Maintenance and repair	Construction with 100% naturalized design
Potential	Ability to Use	Construction with 100% naturalized design	Construction with 100% naturalized design

As it was investigated, the most complex and difficult production division of this part is design. With regard to the existence of advanced programming codes used in this part, naturalized design o this product is much easier than duplication of similar foreign samples. Thus, Iran, having acceptable Infoware and Humanware capabilities in the naturalization of this part, has been able to achieve the ideal naturalization level for turbines less than 1.5 MW. However, due to lack of experience, it has not been able to achieve the necessary capabilities for bigger sized turbines.

4.2.6. Blade

The blade is one of the pivotal parts for wind turbines and due to the high technology necessary for its construction; it can be considered an obstacle for countries' successful naturalization in constructing wind turbines. The wind turbine blade is one of the most important parts which Iran is also having problems with its construction. The only company which has specifically taken any steps in regard to producing this part until today is Saba Niroo Company, having attempted at building the blade for the 660 kW V47 wind turbines. Saba Niroo is the first and only producer of big wind turbines in Iran and the Middle East, having professional technicians and modern production facilities and laboratories; it offers its products under the license of Denmark's Vestas Company. With regard to the current facility level of wind turbine blade production, such as the vacuum furnace, this company has the capability of constructing V47 wind turbine blades with capacity of 660 kW.

Regardless of the entry of one company to this parts construction process, due to the use of composite material and special facilities, the blade is considered a highly technological part and the 100% naturalized production of this product is not possible in Iran. In the manufacturing process of the blade, this company imports the necessary raw material for the production of this type from foreign countries, namely prepreg and resin. Another important part, for which production abilities are not currently available in Iran, is the root joint blade which has been provided from foreign countries until now. However, Saba Niroo Company has recently implemented the production program for this product and has been able to take positive steps in naturalizing this part. After fulfilling manufacturing and assembly facilities and providing the necessary raw material, the first root joint part will be experimentally built with prepreg material and after any probable defects or adjustments are resolved, the main part will be produced. It can be generally stated that the design and production ability of this part does not currently exist in Iran, but by obviating technological gaps, ideal capability levels will be accomplished in the near future.

With regard to strengths and weaknesses which Iran faces regarding the construction of turbines, its effective and potential capabilities in the realm of wind turbine blade construction can be evaluated as follows:

	>3 MW	1.5–3 MW	<1.5 MW
Effective	Awareness of use	Maintenance and repair	Assembly
Potential	Ability to use	Construction with 100% naturalized design	Construction with a percentage of naturalized design

In Iran, providing necessary raw material for the V47 660 kW turbine (such as prepreg) and construction of root joints are considered the most difficult sections of blade production. Availability of these parts and material inside the country is usually difficult due to their high-tech status and need to be imported from other countries. Lack of technical facilities and appropriate knowledge in producing raw materials and root joints can be considered as Technoware, Infoware, and Humanware problems in producing wind turbine blades. These difficulties have resulted in a gap for achieving the ideal level of naturalization for this part.

5. Conclusion

By comparing the development process of using renewable energies in the world and Iran, Iran's lack of development in this realm of energy is completely evident. The oil-bearing characteristic is one of the most important reasons for underdevelopment in using renewable energies in Iran. The existence of abundant fossil fuels has resulted in the charge of high subsidies for using these types of energies. Nevertheless, on one hand, Iran has a high potential in having wind and solar resources. On the other hand, by implementing the economic transition and purposeful subsidies in Iran, the appeal of renewable energies, especially wind and solar energy will experience a significant increase. Therefore, it is anticipated that in future years, renewable energies will have an important role in Iran's energy package.

Another obstacle hindering the development of renewable energies is underdevelopment of technological capabilities for these energies in Iran. Thus one of the necessary steps needed for planning the development of using renewable energies, is evaluating the domestic ability in initiating and developing related technologies. Therefore, in this study, Iran's capability in wind turbine technology is evaluated. This aim will provide a basis for the supportive policies of Iran's turbine manufacturing industry. In fact, decision makers will become aware of support given for Iran's developmental abilities in building the main parts of turbines in line with achieving the level of capability. Also, Iran's potential and effective capabilities for part construction will be a factor for determining the support rate of these parts.

The next step is identifying major strategies for development of domestic capabilities is based on the understanding obtained from existing conditions. Finally, with regard to its major strategies, Iran needs to adapt policies for the use of renewable energies. It seems that existing policies for the support of renewable energies are not sufficient in Iran, and the need for increasing and variating the policy domain is sensed. Reassessment of policies and presenting a policy package for the various aspects of increase in the use of renewable energies, including the formation of the markets and supply of technology is considered a "must" for Iran.

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